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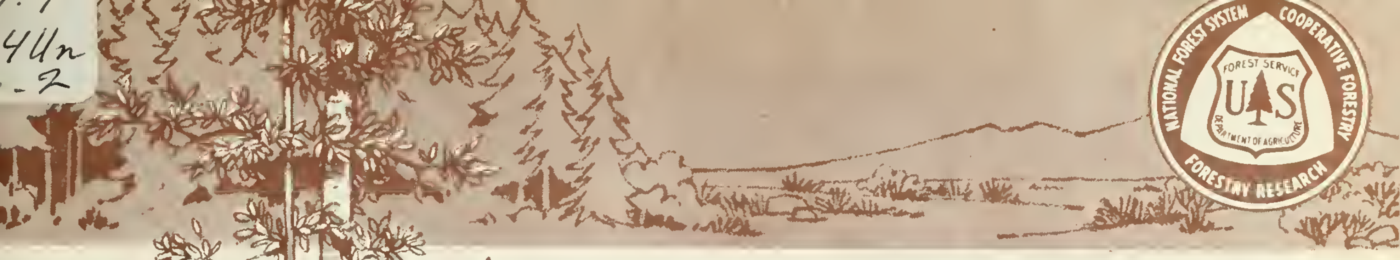

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SPONTANEOUS AND PILOTED IGNITION OF ROTTEN WOOD

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ABSTRACT

*Spontaneous and piloted ignitions of rotten wood samples from ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and subalpine fir (*Abies lasiocarpa*) were investigated in a specially designed ignition furnace. Minimum heat flux intensities required to produce ignition, times to ignition, and temperatures at times of ignition are given.*

KEYWORDS: forest fuel ignition, rotten wood ignition, ignition, pilot ignition, spontaneous ignition.

The process of decay transforms sound wood into a "punky" material that fire managers have long recognized as one of the most troublesome forest fuels. This material, present in all forest types, is important not only because of the ease with which it forms firebrands, but also for its suitability as a firebrand recipient. It is as a recipient where its ease of ignition and the fire holding properties of this material cause fire control forces the most concern. Punky wood has been known to harbour a glowing ignition process for days or even weeks with little or no outward sign of combustion. The necessary environmental conditions may then develop to produce flaming combustion and an eventual problem fire.

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The timber industry is acutely aware of the ignition potential of the rotten wood present at nearly all logging sites. The susceptibility of rotten wood to ignition by carbon particles, hot gases, and contact with hot surfaces was the subject of many early fire research investigations (Doyle 1926; Space 1927; Wright 1932; Fairbanks and Bainer 1934). More recently, power saw ignition of punky wood and other forest floor fuels, particularly in the Pacific Northwest, became of great concern to protection agencies and lumbering concerns. As a result, in 1974, the Northwest Forest Fire Council formed a Power Saw Spark Arrester Committee composed of representatives of the Federal and State Protection agencies in the States of Washington, Oregon, and California, the Washington and Oregon Forest Protection Associations, and several forest industries. The Engineering Committee of the Power Saw Manufacturer's Association was contacted and cooperative efforts were begun to alleviate the problem.

The primary objective of the Power Saw Spark Arrester Committee was to determine acceptable temperature standards for power saw exhaust systems. Instrumentation and procedures developed at the Northern Forest Fire Laboratory for the investigation of ignition properties of fine forest fuels were directly applicable to this determination (Stockstad and Lory 1970; Stockstad 1972, 1973, 1975, 1976). The portions of a study utilizing rotten wood as the test fuel are reported in this paper. The data and conclusions presented were used by the committee to formulate new temperature standards for power saw exhaust systems. These standards were in turn used by the National Society of Automotive Engineers, the Departments of Natural Resources of the States of Washington and Oregon, and the USDA Forest Service to adopt or amend regulatory standards for power saw exhaust systems (National Society of Automotive Engineers 1976; Washington State Department of Natural Resources 1976; Oregon State Department of Natural Resources 1976; USDA Forest Service 1976).

OBJECTIVES

The objectives of this study were to determine:

1. The time required for ignition to occur in rotten wood,

2. The surface temperatures at the onset of ignition, and

3. The effect of fuel moisture content and initial heat source intensity on items 1 and 2 above.

PROCEDURES

The Stockstad-Lory ignition furnace (Stockstad and Lory 1970; Stockstad 1972, 1973) was used for all testing. Both spontaneous and pilot ignition were studied using a 2.54 cm by 0.25 cm by 0.25 cm (1-inch by 0.1-inch by 0.1-inch) section of rotten wood. Spontaneous and piloted ignition tests were replicated 20 times for each moisture level and furnace temperature under consideration.

Tree species used in the testing were ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Psuedotsuga menziesii*), and subalpine fir (*Abies lasiocarpa*). Ponderosa pine and Douglas-fir samples both were obtained from the Blue Mountain and Mill Creek areas in the vicinity of Missoula, Montana; subalpine fir samples were obtained near Lolo, Montana.

Samples were obtained by cutting 0.25 cm (0.10-inch) thick slabs from visually uniform pieces of rotten wood. A standard 35.56 cm (14-inch) band saw with a special 24-tooth per 2.54 cm (1-inch) blade was used for this operation. The fine tooth blade was necessary to assure a successful cut through the fragile sample. The slab was then cut into 0.25 cm by 0.25 cm (0.10-inch by 0.10-inch) strips using a modified high speed (30,000 rpm) hand tool to drive a miniature circular saw 0.013 cm (0.005-inch) thick and 2.54 cm (1-inch) in diameter. This same tool was used to cut the strips into 2.54 cm (1-inch) lengths for testing. The use of this special saw was the only successful method that could be found to cut strips from the sample material. All samples were kept at an ambient laboratory air temperature prior to conditioning for testing.

Prepared sections were placed in conditioning cabinets containing saturated salt solutions (Schuette 1965) to provide three moisture levels of approximately 6, 14, and 23 percent. Moisture content was determined on an oven-dry weight basis using the conventional oven dry method.

The minimum furnace temperature used for each moisture content in the testing program was that at which ignitions were not observed in 20 trials. Each trial was allowed to continue until ignition occurred or for a 3-minute time interval. (Preliminary testing had indicated ignition would usually occur in less than a 1-minute interval.) Furnace temperature then was raised 10°C and another series of 20 tests were observed. This procedure was repeated until a furnace temperature was reached at which all samples of a given species and moisture level ignited.

Sample temperature was measured by a 3-mil platinum vs platinum 10-percent rhodium thermocouple placed on the forward end of the sample. The ignition chamber temperature, synonymous with furnace temperature, was measured by a similar thermocouple approximately 3 mm (0.118 inches) from the sample thermocouple (Stockstad 1972). Both thermocouples were connected to a recorder and the output was plotted against time.

Three points on the plotted thermocouple traces from a spontaneous ignition test were considered in the analysis:

1. Point one.--The point at which the sample thermocouple trace crossed and exceeded the ignition chamber trace was considered to be the beginning of the exothermic reaction. This point was considered to be indicative of the lowest temperature at which the ignition process could occur.

2. Point two.--The second significant change in the sample thermocouple trace was the point where the exothermic reaction increased in intensity and resulted in an abrupt rise in the temperature of the sample. This point was considered to represent the time and temperature at which the spontaneous ignition process would always continue to the end result--visible glowing.

3. Point three.--An event marker activated by the test operator that indicated the time and temperature at which visible glowing was observed.

Pilot ignition tests were conducted in the same manner as spontaneous ignition tests, except for the introduction of a pilot flame (Stockstad 1972). Pilot ignition usually occurred at temperatures below actual furnace temperature; therefore, the beginning of the exothermic reaction, if one occurred, could not be determined by the previously described criteria. The point at which flaming ignition took place was marked by an abrupt, nearly vertical rise in the trace. For this reason, an operator-activated event marker was not necessary for the pilot ignition testing.

RESULTS

The results of the 630 spontaneous ignition tests and the 200 pilot ignition tests are given in appendix tables 1 through 6.

The minimum temperature at which spontaneous ignition occurred was 270°C (518°F) for ponderosa pine, 260°C (500°F) for Douglas-fir, and 300°C (572°F) for subalpine fir rotten wood sections. One hundred percent of all samples tested were spontaneously ignited at temperatures of 320°C (608°F) for ponderosa pine, 300°C (572°F) for Douglas-fir, and 330°C (626°F) for subalpine fir. The moisture content of the samples varied.

An increase of 10°C (18°F) in furnace temperature usually resulted in a marked increase in the number of samples that ignited. In the case of the ponderosa pine samples from Elk Ridge, a furnace temperature increase of 10°C (18°F) resulted in the probability of ignition increasing from approximately 25 percent to 100 percent; a 20°C (36°F) rise increased the probability of ignition from 0 percent to 100 percent. The probability of ignition increase was not as dramatic for the other samples tested, but remained abrupt.

Figure 1 shows the relation between the time required for spontaneous ignition to occur at the various moisture content levels of the different samples tested. The furnace temperatures at which 100 percent of all samples ignited were used for comparison.

Analysis of variance (at the 95 percent level of confidence) did not show a significant difference for the times and temperatures at spontaneous ignition among the Elk Ridge area, ponderosa pine samples having a variety of moisture contents. A significant difference did exist for both time and temperature at spontaneous ignition for all others samples and different moisture contents.

Further analysis using the Tukey's Test (Steel and Torrie 1960) revealed a significant difference to exist for all samples (other than those from Elk Ridge) in time-to-ignition between the lowest and highest moisture content samples examined. The significance also existed between the low and medium moisture contents for the ponderosa pine and Douglas-fir samples from the Mill Creek area, but not for the Douglas-fir from the Blue Mountain area nor the subalpine fir from the Lolo Creek area. For the samples from the latter two areas, the significance did exist between the medium and high moisture contents.

Tukey's Test also revealed a significant difference to exist for all samples (except the Elk Ridge samples) in the temperature at spontaneous ignition for the lowest and highest moisture content samples examined. Significant differences also existed between the lowest and medium moisture content samples in the case of ponderosa pine and Douglas-fir samples from Mill Creek, but did not exist for the Douglas-fir from Blue Mountain nor the subalpine fir from Lolo Creek. A significant difference existed for the medium and high moisture content samples of Mill Creek ponderosa pine and Douglas-fir, and the subalpine fir samples from Lolo Creek.

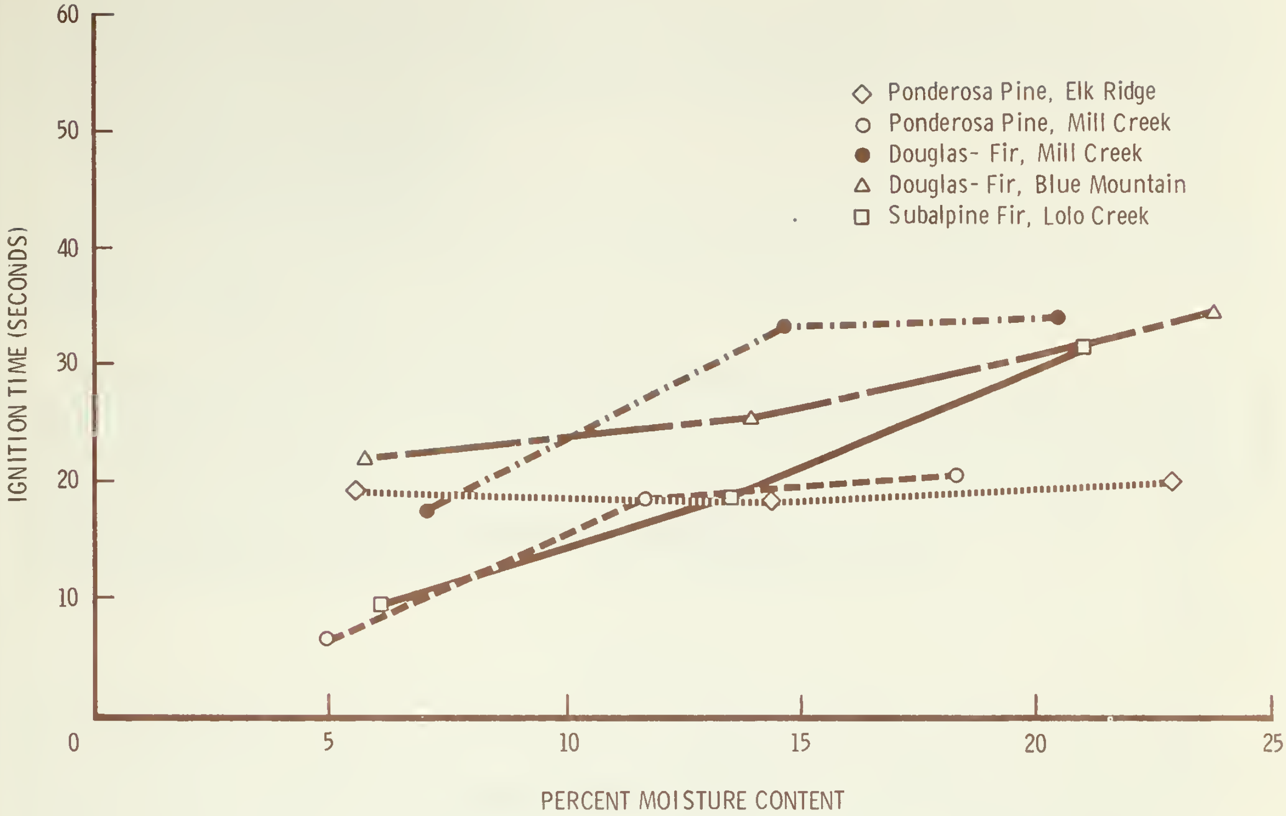

Figure 1.--Time to spontaneous ignition vs. moisture content for various rotten wood sections--100 percent of all samples igniting.

The minimum furnace temperature at which pilot ignition occurred was 250°C (482°F) for the Blue Mountain area Douglas-fir samples and 260°C (500°F) for the Elk Ridge area, ponderosa pine samples. A furnace temperature of 270°C (518°F) was necessary to produce 100 percent ignition of all samples at the moisture contents examined. A rise of 10°C (18°F) in furnace temperature resulted in an increase of ignitions from 20 to 40 percent to 100 percent for the ponderosa pine samples and a 20°C (36°F) increase, increased ignitions on the Douglas-fir samples from 0 to 5 percent to 100 percent.

Figure 2 shows the relations between the average times required for pilot ignition to occur for all moisture contents of the Douglas-fir and ponderosa pine samples tested. The furnace temperature used for comparison purposes was 270°C (518°F), the temperature at which 100 percent of all samples ignited.

Analysis of variance at the 95 percent level of confidence did not show a significant difference for either the time to, or the temperature at, pilot ignition for the ponderosa pine samples from the Elk Ridge area. The Douglas-fir samples from the Blue Mountain area exhibited a significant difference for the temperature of ignition but not for time-to-ignition. Additional analysis using Tukey's Test revealed the significance for the temperature of ignition for the Douglas-fir samples to exist for the lowest and highest moisture contents tested, but not for the lowest vs medium or the medium vs the highest moisture contents.

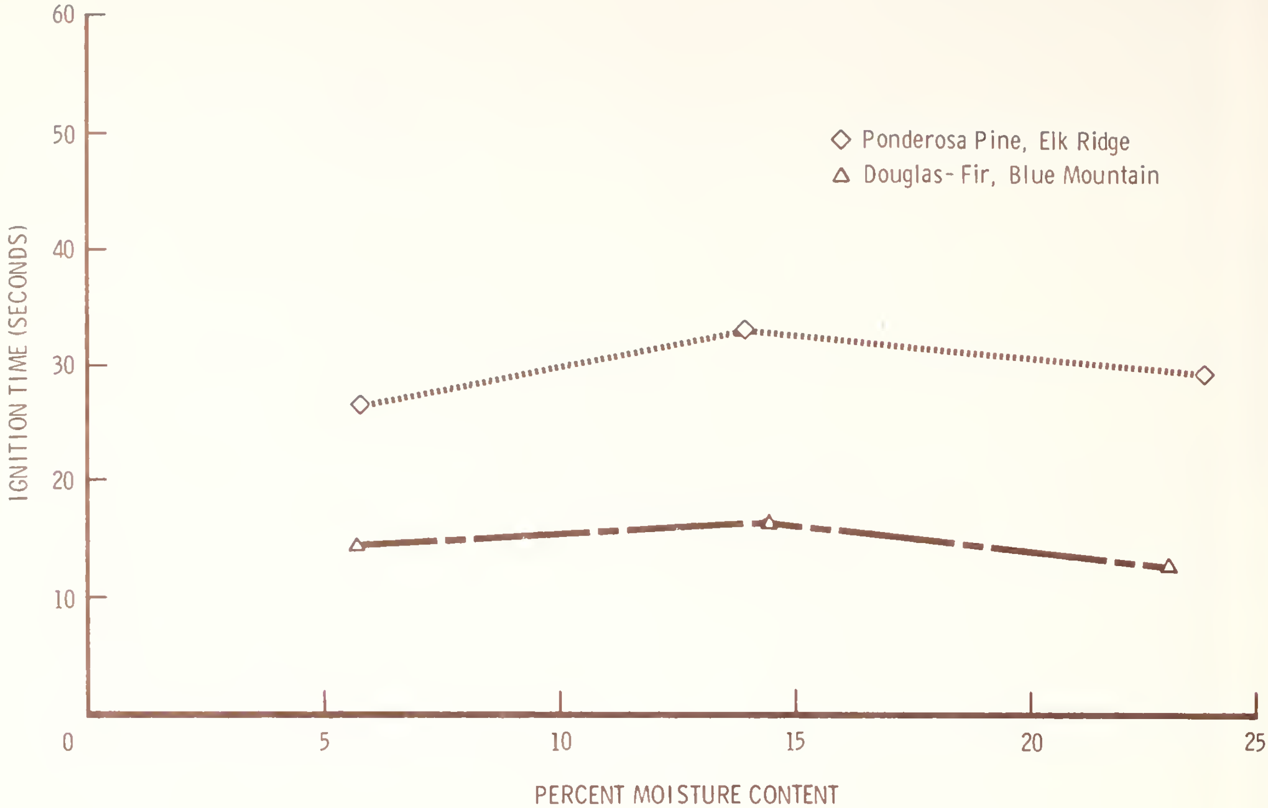

Figure 2.--Time to pilot ignition vs moisture content for various rotten wood sections--100 percent of all samples igniting.

DISCUSSION

In appendix tables 7 and 8 the average heat transfer coefficients are listed. Also listed are the average temperatures, existing at the start of the exothermic reaction in the spontaneous ignition process and at the moment of flaming ignition in the pilot ignition process. Values are given for each of the moisture contents examined for each of the various fuels tested. A minimum of 0.263 cal/cm^2/s produced spontaneous ignition in the Mill Creek Douglas-fir sample with 20.5 percent moisture content. A maximum of 0.327 cal/cm^2/s was necessary to produce spontaneous ignition in a ponderosa pine sample having an 18.2 percent moisture content. The minimum necessary to produce pilot ignition was 0.234 cal/cm^2/s for a ponderosa pine sample with 14.3 percent moisture content. The maximum necessary to produce pilot ignition was the 0.285 cal/cm^2/s required for a Douglas-fir sample with a 5.7 percent moisture content.

In appendix table 9 the total heat in cal/cm^2 and total calories necessary to produce ignition in the various fuel samples tested are listed. Values for both spontaneous and pilot ignition are given.

An average total of 14.7 calories was required to produce spontaneous ignition in the Blue Mountain Douglas-fir samples while the Mill Creek ponderosa pine required an average total of 23.6 calories. Pilot ignition was produced in the Elk Ridge ponderosa pine with an average total of only 10.1 calories while the Blue Mountain Douglas-fir required an average total of 22.0 calories--more that two times greater than the number of calories required for pilot ignition of the Elk Ridge ponderosa pine.

Density determinations had been made on the test samples. These determinations were examined in an attempt to explain the large differences in the heat required for ignition. The density of the Blue Mountain Douglas-fir samples was determined to be 0.332 as compared to the Mill Creek ponderosa pine density of 0.301. This difference in density was not deemed to be of sufficient magnitude to explain the difference in total heat required for ignition.

The difference in total heat required for pilot ignition also is not readily explained by density relations. The Elk Ridge ponderosa pine density was 0.247. The Douglas-fir Blue Mountain samples had a density of 0.332. The greater density material required more than twice the amount of heat for ignition, which is in contrast to the findings of Simms (1963).

The true effect of density on the ignition process in forest fuels is probably masked by a host of uncontrollable and unknown variables. Both the type and degree of decay can differ widely within the same piece of wood. For example, the density of the Mill Creek ponderosa pine sample-sections ranged from 0.234 to 0.457 and averaged 0.301; such a spread could easily mask any apparent differences among species. The presence of varied amounts of volatiles in individual test sections as well as among samples species also could mask the density difference relations.

CONCLUSIONS

The belief that rotten wood is one of the most easily ignitable fuels in the forest complex has been upheld by this study. Spontaneous ignition in an isothermal atmosphere occurred with temperatures as low as 260°C (500°F) for the Douglas-fir samples tested. Pilot ignition in the same fuel occurred with temperatures as low as 250°C (482°F).

A heat source capable of producing 0.358 cal/cm^2/s for 34 seconds may cause spontaneous ignition in Douglas-fir rotten wood having a moisture content near 24 percent. Samples with 6 percent moisture content may be ignited with a heat source capable of producing 0.325 cal/cm^2/s for only 22 seconds. Ponderosa pine rotten wood with 6 percent moisture content may be spontaneously ignited by a heat flux of 0.306 cal/cm^2/s of 13 seconds duration; samples with 23 percent moisture content required 0.402 cal/cm^2/s for 41 seconds. Subalpine fir rotten wood with a 6 percent moisture content ignited in 9 seconds when subjected to a heat flux of 0.358 cal/cm^2/s.

Pilot ignition of rotten wood occurred even more readily. A heat source capable of producing 0.287 cal/cm^2/s for only 16 seconds produces ignition in ponderosa pine samples having moisture content to 23 percent. Douglas-fir rotten wood will ignite with the same intensity heat source but requires 33 seconds.

The time to spontaneous ignition as related to moisture content was found to be significantly longer as moisture content of the samples increased beyond the 13 to 15 percent level. Significant difference was not found to exist for moisture contents of approximately 5 percent to 14 percent. The significance did not exist for the time to pilot ignition vs moisture content relation.

From the above the conclusion can be drawn that increasing moisture contents to 15 percent have negligible effect on spontaneous or pilot ignitions of rotten wood. Moisture contents greater than 15 percent to approximately 24 percent delay the time to spontaneous ignition but not for pilot ignition.

From this we can conclude that the probability of spontaneous ignition in rotten wood does not significantly decrease with increasing moisture contents to approximately 15 percent but will decrease for moisture contents from 15 percent to 24 percent, the highest level that was tested. The pilot ignition procedure for rotten wood as determined by the test procedures was not found to be significantly affected by moisture contents to 24 percent.

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Table 1.--*Percentage of spontaneous ignitions of various rotten wood sections at selected furnace temperatures for 20 tests per moisture content*

Fuel sample	Moisture content	Furnace temperature								
		250	260	270	280	290	300	310	320	330
	Percent	°C								
Ponderosa pine, Elk Ridge	5.6						0	15	100	
	14.3						0	35	100	
	22.8						0	20	100	
Ponderosa pine, Mill Creek	4.8		0	15	15	90	100			
	11.6		0	5	0	10	20	45	100	
	18.2			0	0	15	35	60	100	
Douglas-fir, Mill Creek	6.9		0	0	0	95	100			
	14.6	0	5	35	25	100				
	20.5		0	30	10	100				
Douglas-fir, Blue Mountain	5.7			0	35	95	100			
	13.8				0	70	100			
	23.7				0	75	100			
Subalpine fir, Lolo Creek	6.0					0	5	40	45	100
	13.4					0	10	40	60	100
	21.0					0	15	40	100	

Table 2.--*Time to spontaneous ignition of various rotten wood sections at various moisture contents--100 percent of all samples igniting*

Fuel sample	Moisture content	Start of exothermic reaction	Sharp rise in trace	Visual glowing	Furnace temperature
	Percent	*Seconds*			°C
Ponderosa pine, Elk Ridge	5.6	19.0	57.9	60.6	320
	14.3	18.1	52.4	54.0	320
	22.8	20.0	59.5	62.9	320
Ponderosa pine, Mill Creek	4.8	12.9	36.8	40.8	300
	11.6	37.0	72.8	78.0	320
	18.2	41.1	62.4	67.9	320
Douglas-fir, Mill Creek	6.9	17.1	40.2	47.1	300
	14.6	33.8	53.5	59.6	290
	20.5	34.4	51.0	55.2	290
Douglas-fir, Blue Mountain	5.7	21.9	43.6	50.0	300
	13.8	25.2	43.9	48.2	300
	23.7	34.2	52.8	58.4	300
Subalpine fir, Lolo Creek	6.0	9.1	36.7	38.8	330
	13.4	18.4	42.6	46.4	330
	21.0	30.2	57.8	61.6	320

Table 3.--*Temperatures at time of spontaneous ignition of various rotten wood sections at various moisture contents--100 percent of all samples igniting*

Fuel sample	Moisture content	Start at exothermic reaction	Sharp rise in trace	Visual glowing	Furnace temperature
	Percent	- - - - - - - - - - *°C*	- - - - -	- - - - -	- - - - -
Ponderosa pine, Elk Ridge	5.6	280	320	333	320
	14.3	268	313	326	320
	22.8	279	316	332	320
Ponderosa pine, Mill Creek	4.8	250	286	313	300
	11.6	252	288	312	320
	18.2	287	315	338	320
Douglas-fir, Mill Creek	6.9	250	294	356	300
	14.6	250	267	300	290
	20.5	248	267	290	290
Douglas-fir, Blue Mountain	5.7	252	286	340	300
	13.8	256	287	325	300
	23.7	256	276	300	300
Subalpine fir, Lolo Creek	6.0	268	314	333	330
	13.4	282	307	325	330
	21.0	283	305	315	320

Table 4.--*Percentage of pilot ignitions of various rotten wood sections at selected furnace temperatures for 20 tests per moisture content*

Fuel sample	Moisture content	Furnace temperature			
		240	250	260	270
	Percent	- - - - - - *°C*	- - - - -	- - - - -	- - - - -
Ponderosa pine, Elk Ridge	5.6		0	40	100
	14.3		0	20	100
	22.8		0	20	100
Douglas-fir, Blue Mountain	5.7		0	90	100
	13.8	0	5	60	100
	23.7	0	5	65	100

Table 5.--*Time to pilot ignition of various rotten wood sections at various moisture contents--100 percent of all samples igniting*

Fuel sample	Moisture content	Time to flaming ignition	Furnace temperatures
	Percent	*Seconds*	*°C*
Ponderosa pine, Elk Ridge	5.6	14.2	270
	14.3	16.1	270
	22.8	13.0	270
Douglas-fir, Blue Mountain	5.7	26.8	270
	13.8	33.1	270
	23.7	29.2	270

Table 6.--*Temperatures at time of pilot ignition of various rotten wood sections at various moisture contents--100 percent of all samples igniting*

Fuel sample	Moisture content	Temperature of ignition	Furnace temperature
	Percent	*°C*	*°C*
Ponderosa pine,	5.6	241	270
Elk Ridge	14.3	233	270
	22.8	237	270
Douglas-fir,	5.7	278	270
Blue Mountain	13.8	267	270
	23.7	255	270

Table 7.--*Average heat flux and temperature at initiation of exothermic reaction during spontaneous ignition of rotten wood sections--100 percent ignition of all samples*

Fuel sample	Moisture content	Heat flux	Start of exothermic reaction	Furnace temperature
	Percent	*Cal/cm²/s*	*°C*	*°C*
Ponderosa pine,	5.6	0.318	280	320
Elk Ridge	14.3	.303	268	320
	22.8	.316	279	320
Ponderosa pine,	4.8	.266	250	300
Mill Creek	11.6	.283	252	320
	18.2	.327	287	320
Douglas-fir,	6.9	.266	250	300
Mill Creek	14.6	.266	250	300
	20.5	.264	248	290
Douglas-fir,	5.7	.268	252	300
Blue Mountain	13.8	.268	252	300
	23.7	.273	256	300
Subalpine fir,	6.0	.308	268	330
Lolo Creek	13.4	.326	282	330
	21.0	.322	283	320

Table 8.--*Average heat flux and temperature at flaming ignition during pilot ignition of rotten wood sections--100 percent of all samples igniting*

Fuel sample	Moisture content	Heat flux	Flaming ignition	Furnace temperature
	Percent	*Cal/cm²/s*	- - - - - *°C*	- - - - - - -
Ponderosa pine, Elk Ridge	5.6	0.243	241	270
	14.3	.234	233	270
	22.8	.238	237	270
Douglas-fir, Blue Mountain	5.7	.285	278	270
	13.8	.272	267	270
	23.7	.258	255	270

Table 9.--*Average total heat needed to produce spontaneous and pilot ignition in various rotten wood sections--all ignitions included*

Fuel sample	Type of ignition	Total heat required for ignition	
		Cal/cm²	*Calories*
Ponderosa pine, Elk Ridge	Spontaneous	5.5	14.9
Ponderosa pine, Mill Creek	Spontaneous	8.8	23.6
Douglas-fir, Mill Creek	Spontaneous	7.4	17.0
Douglas-fir, Blue Mountain	Spontaneous	6.4	14.7
Subalpine fir, Lolo Creek	Spontaneous	5.6	15.0
Ponderosa pine, Elk Ridge	Pilot	3.8	10.1
Douglas-fir, Blue Mountain	Pilot	9.6	22.0

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